9 Comparison of Realizations of the Terrestrial Reference Frame

C. Ma, D. MacMillan, S. Bolotin, K. Le Bail, D. Gordon, and J. Gipson

Abstract

IGN and DGFI both generated realizations of the terrestrial reference frame under the auspices of the IERS from combination of the same space geodetic data. We compared the IGN and DGFI TRFs with a GSFC CALC/SOLVE TRF. WRMS position and velocity differences for the 40 most frequently observed sites were 2–3 mm and 0.3–0.4 mm/year. There was a scale difference of −0.39/−0.09 ppb between the IGN/DGFI realizations and the GSFC solution. When we fixed positions and velocities to either the IGN or DGFI values in CALC/SOLVE solutions, the resulting EOP estimates were not significantly different from the estimates from a standard TRF solution.

Keywords

Radio wave technique • Terrestrial reference frame • Space geodesy

1 Introduction

Recently IGN generated ITRF2008, the latest version of the IERS international terrestrial reference frame. This frame is a combination solution based on input from the VLBI, SLR, GPS, and DORIS technique combination analysis centers. For this realization of the TRF (Terrestrial Reference Frame), the input consisted of the technique EOP (Earth orientation parameters) and station position time series as well as the available site tie vectors. To provide an alternative to cross-check the IGN solution, DGFI also generated a combination TRF, DTRF2008, from the same input data available to IGN.

In this paper we evaluate ITRF2008 and DTRF2008, by comparing them with CALC/SOLVE (Ma et al. 1990) VLBI TRF solutions and by investigating the effects of applying the two ITRFs in VLBI solutions. Essentially, we investigate how well the VLBI information provided to the combination is recovered. In Sect. 2, we directly compare the site positions and velocities from the IGN and DGFI solutions with those from a standard VLBI solution. In Sect. 3, we examine the EOP series estimated from solutions in which the TRF positions and velocities are not estimated but are instead fixed to ITRF2008 or DTRF2008. In Sect. 4, we summarize our conclusions.

C. Ma (✉)
NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
e-mail: chopo.ma@nasa.gov

D. MacMillan • S. Bolotin • K. Le Bail • D. Gordon • J. Gipson
NVI, Inc. and NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

2 Comparisons of TRFs

For our comparisons, we ran an operational-type VLBI TRF solution with the CALC/SOLVE software using data from 1979 until February 2010. The solution estimated global positions and velocities and source positions from the entire time period as well as EOP. We then compared this VLBI TRF with the positions and velocities extracted from the ITRF2008 and DTRF2008 SINEX files. Tables 9.1 and 9.2 show the position and velocity Helmert 7-parameter transformation values between the VLBI TRF and the IGN or DGFI TRFs. One significant difference is the scale difference of -0.39 ± 0.15 ppb for the IGN solution. For DGFI, the scale difference was only -0.09 ± 0.10 ppb. Translating

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Table 9.1 Seven-parameter position transformation at epoch 2005

	IGN–VLBI	DGFI–VLBI
T_x (mm)	−0.04 ± 1.1	+0.8 ± 0.7
T_y (mm)	−1.7 ± 1.0	−1.4 ± 0.7
T_z (mm)	+0.8 ± 0.9	−0.5 ± 0.6
R_x (mm)	−5.7 ± 1.2	−5.9 ± 0.8
R_y (mm)	+1.6 ± 1.2	+0.3 ± 0.8
R_z (mm)	−1.9 ± 1.2	+2.5 ± 0.8
Scale (ppb)	−0.39 ± 0.15	−0.09 ± 0.10
Scale		

Table 9.2 7-Parameter velocity transformation

	IGN–VLBI	DGFI–VLBI
$\dot{T}_x$ (mm/year)	−0.39 ± 0.11	+0.07 ± −0.07
$\dot{T}_y$ (mm/year)	−0.56 ± 0.10	−0.13 ± 0.07
$\dot{T}_z$ (mm/year)	−0.25 ± 0.10	−0.30 ± 0.08
$\dot{R}_x$ (mm/year)	−0.27 ± 0.13	−0.30 ± 0.08
$\dot{R}_y$ (mm/year)	+0.00 ± 0.12	+0.14 ± 0.08
$\dot{R}_z$ (mm/year)	+0.15 ± 0.10	−0.06 ± 0.08
Scale (ppb/year)	+0.023 ± 0.016	−0.005 ± 0.010

to site vertical, the IGN discrepancy corresponds to about 2.5 mm. The scale differences must arise from the treatment of scale in the respective combinations. IGN found an SLR–VLBI scale difference of −1.05 ± 0.13 ppb and for the combination, they weighted the VLBI and SLR scales equally (Altamimi et al. 2010; this issue). In contrast, DGFI found essentially no difference in VLBI and SLR scale so that the difference in scale between DTRF2008 and VLBI (SLR) was 0.01 ± 0.03 ppb (0.02 ± 0.03 ppb) respectively (Seitz et al. 2010, this issue). Since VLBI is insensitive to geocenter, the translation differences are due to differences between ITRF2008, DTRF2008, and the a priori coordinates used in the TRF solution. The IGN (DGFI) velocity transformation parameters are all less than 0.6 (0.3) mm/year, where the formal uncertainties are ~0.1 mm/year.

After removing the effect of the seven-parameter transformations, there are some significant residual differences between the VLBI TRF and the IGN and DGFI solutions. In Figs. 9.1, 9.2, 9.3 and 9.4, we show the horizontal and vertical residual differences for sites that observed in at least 20 observing sessions. Differences less than 5 mm are indicated by open circles. The displacement vector differences for larger residuals are plotted. The largest differences for both IGN and DGFI solutions are mainly for Japanese network sites and for US mobile VLBI sites, which observed in the 1980s and early 1990s. The residual 3D differences between the IGN/DGFI solution and the VLBI TRF solution were less than 10 mm for 49/45 sites and greater than 10 mm for 66/64 sites. The number of sessions for the 40 most frequently observed sites ranged from 123 to 2,386 sessions. For these sites, the WRMS of the residual

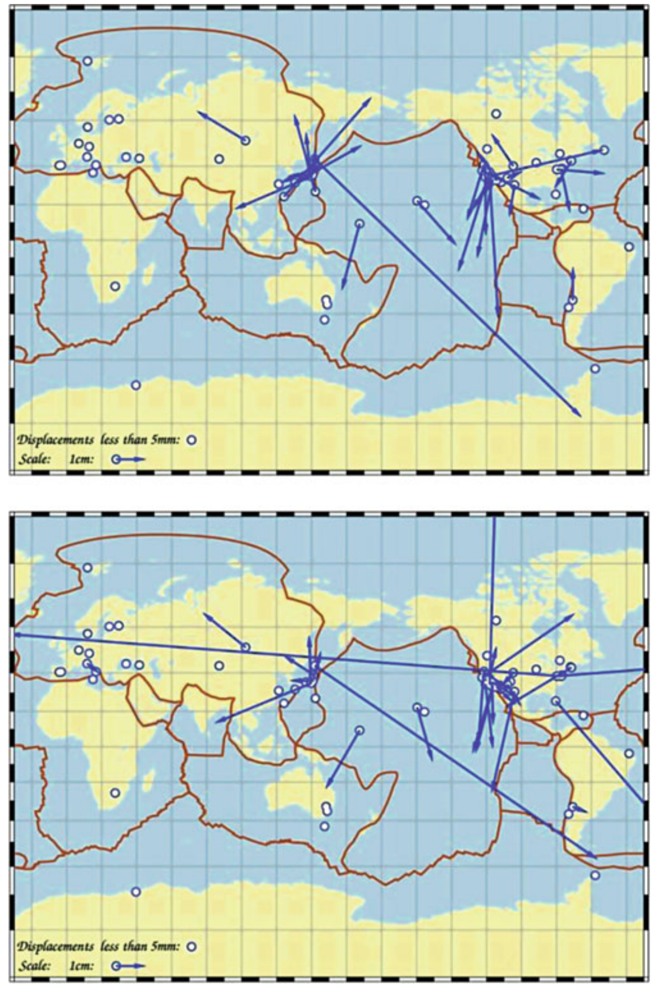

Fig. 9.1 IGN (*upper*) and DGFI (*lower*) horizontal residual vectors (mm) relative to VLBI TRF solution

differences in NEU positions (velocities) for the IGN solution were 1.6 mm (0.3 mm/year), 2.4 mm (0.3 mm/year), and 2.8 mm (0.4 mm/year). For the DGFI solution the NEU residual WRMS values were 2.2 mm (0.3 mm/year), 1.8 mm (0.3 mm/year), and 3.1 mm (0.4 mm/year). For comparison, the VLBI analysis center solution height estimates differed from the IVS ITRF2008 combination solution by 1–2 mm in WRMS (Böckmann et al. 2010).

3 Effects of IGN and DGFI TRFs in VLBI Solutions

In our standard VLBI TRF solutions, we estimate a TRF along with EOP and a CRF (celestial reference frame). In this way, EOP connect the estimated TRF and CRF in a self-consistent way. To evaluate the ITRF2008 solutions, we ran two additional solutions in which we fixed the positions and velocities to those in either the IGN or DGFI solution TRF and then estimated EOP and the CRF. For sites where there

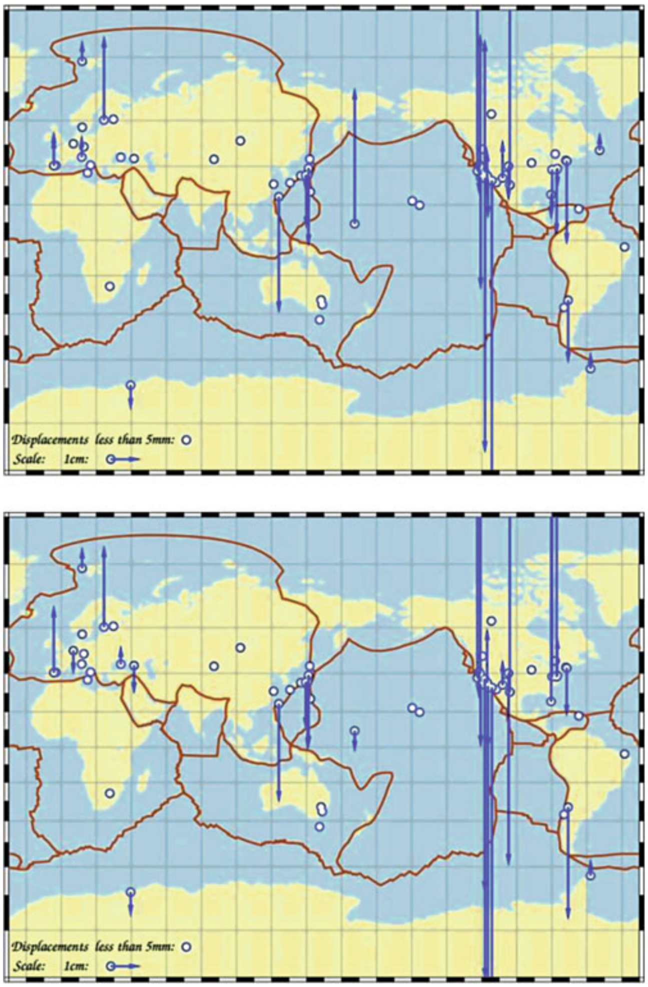

Fig. 9.2 IGN (*upper*) and DGFI (*lower*) vertical position (mm) relative to VLBI TRF solution

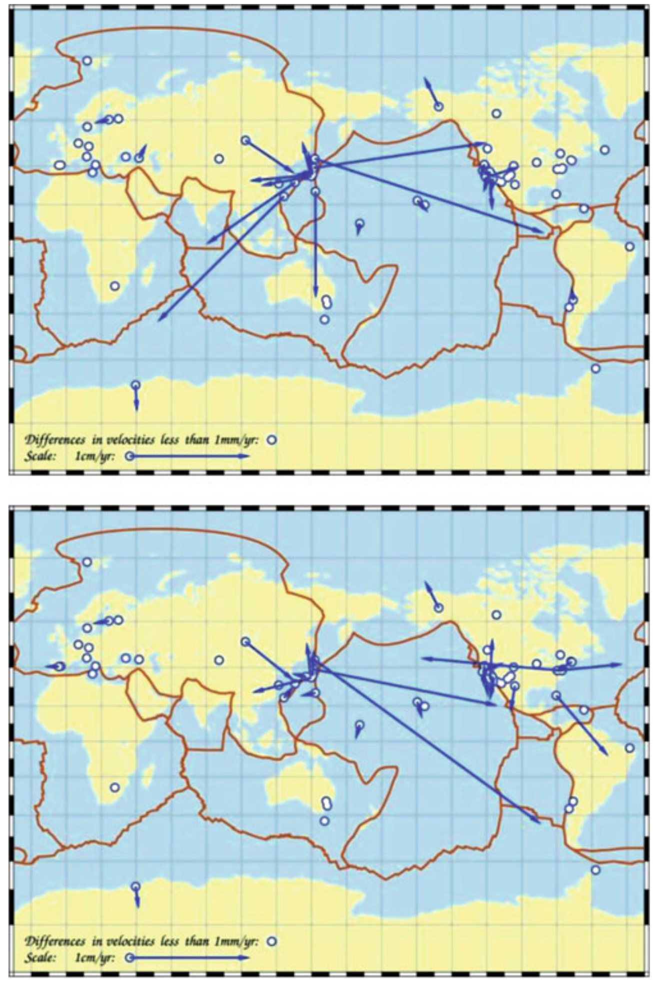

Fig. 9.3 IGN (*upper*) and DGFI (*lower*) horizontal velocity vectors (mm/year) relative to the VLBI TRF solution

were episodic jumps, we applied the jumps given in the DGFI and IGN SINEX files. In the case of Fairbanks, where there was nonlinear postseismic motion after the Denali Earthquake in 2002, we applied the models determined by DGFI or IGN that each consisted of series of XYZ offsets and rates.

As expected, the overall solution fit was best for the standard VLBI solution (22.500 ps) since the TRF was estimated. Fixing the TRF to the DGFI a priori gave a solution residual WRMS fit of 22.650 ps, which was somewhat better than fixing to the IGN a priori which had a fit of 22.733 ps. The IGN 24-h session fits were especially bad for a number of Japanese network sessions. Generally the IGN and DGFI solution daily session WRMS residual fits were similar. Figure 9.5 shows the distribution of the (DGFI-IGN) differences in session fits. Solution fits were slightly better using the DGFI positions and velocities. Typically, 24-h-session solution fits are 20–40 ps. However, the solution fits for many domestic Japanese network sessions were significantly worse for the IGN solution because some of the Japanese station positions (for example, AIRA, GIFU3, SINTOTU2, CHICHI10) were much different from the GSFC VLBI TRF positions as seen in Fig. 9.1.

We compared EOP estimates from the three solutions (IGN, DGFI, VLBI TRF) with the IGS EOP time series. As summarized in Table 9.3, the agreement between the IGS series and the IGN and DGFI series are not significantly different. The χ^2 are greater than 1 mainly because the combined formal EOP uncertainties are too small. VLBI sigmas are small by a factor of 1.5–1.7 and IGS sigmas of 15–30 μas are also too small. IGS agreement with the GSFC VLBI TRF EOP series is slightly better. For X-pole and Y-pole, we also computed as a function of sampling time the Allan variance (Allan 1966, 1987; Le Bail 2006) of the differences between each of the three EOP series and the IGS series. The results shown in Fig. 9.6 indicate that there is no significant difference (much less than one-sigma) between the three solutions and the IGS series.

The Allan variance of the differences between polar motion estimates from the IGN or DGFI solutions and the GSFC VLBI TRF solution are shown in Fig. 9.7. Given the formal uncertainties of the Allan variance, there is no

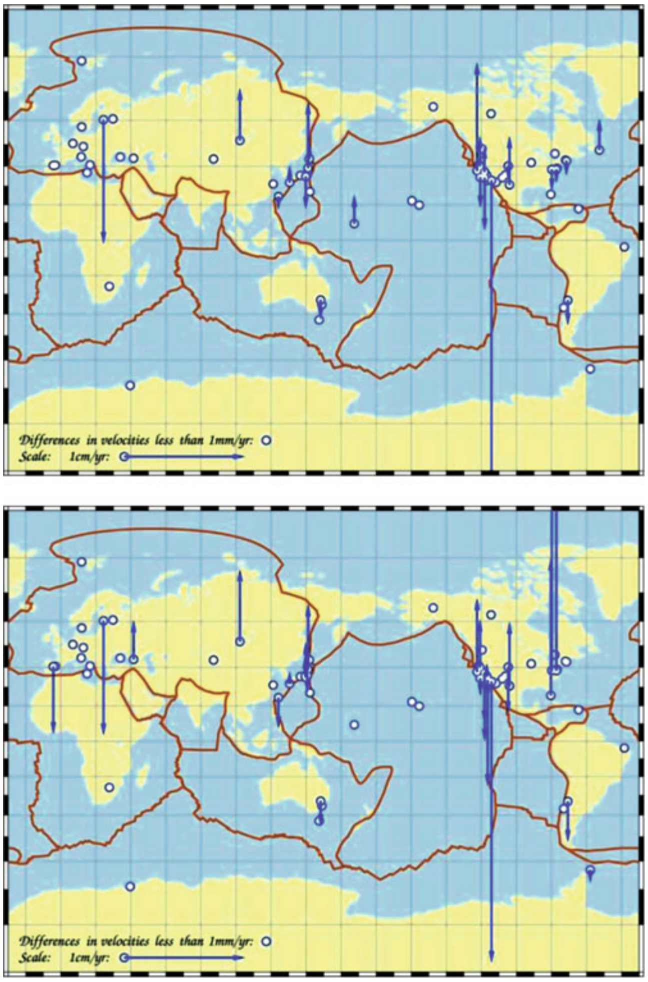

Fig. 9.4 IGN (*upper*) and DGFI (*lower*) vertical rates (mm/year) relative to the VLBI TRF solution

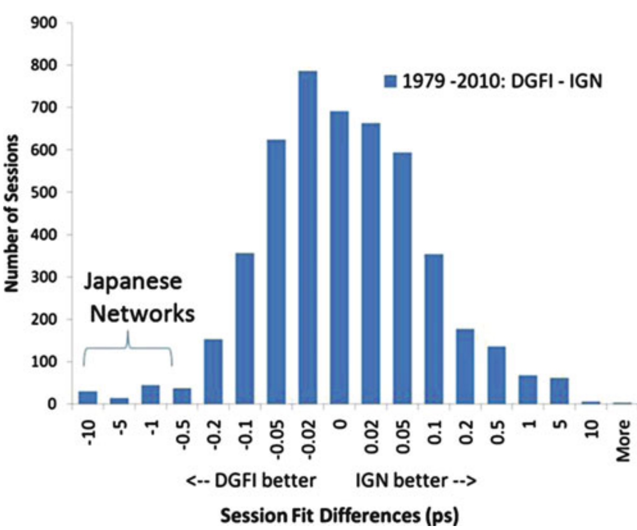

Fig. 9.5 Distribution of differences between 24-h session fits for solutions in which the TRF was fixed to either the IGN or DGFI positions and velocities

Table 9.3 EOP differences with IGS EOP series

	VLBI TRF		DGFI		IGN	
	WRMS	χ^2	WRMS	χ^2	WRMS	χ^2
X, µas	115	3.1	118	3.9	117	3.8
Y, µas	116	3.4	118	4.3	118	4.3
LOD, µs/d	19.7	3.7	19.7	3.7	19.8	3.7

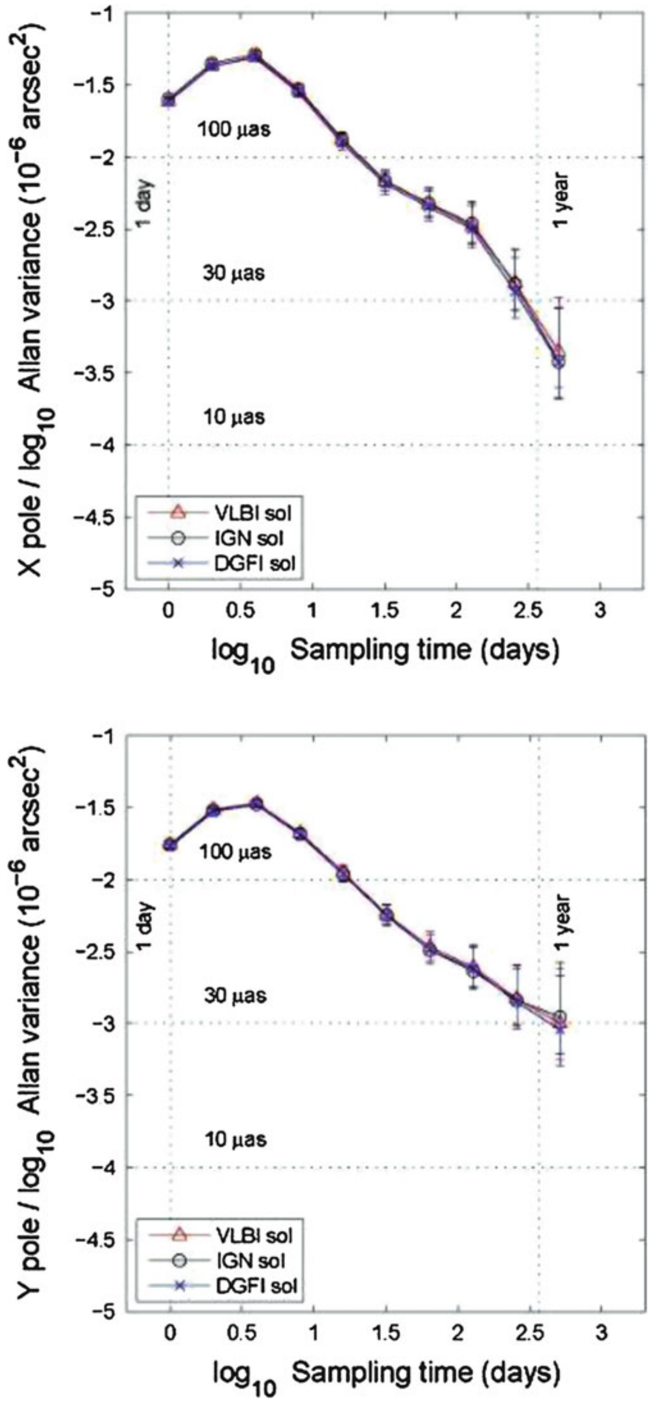

Fig. 9.6 Allan variances of X-pole and Y-pole differences between each of the solutions (VLBI TRF, IGN, DGFI) and the IGS series

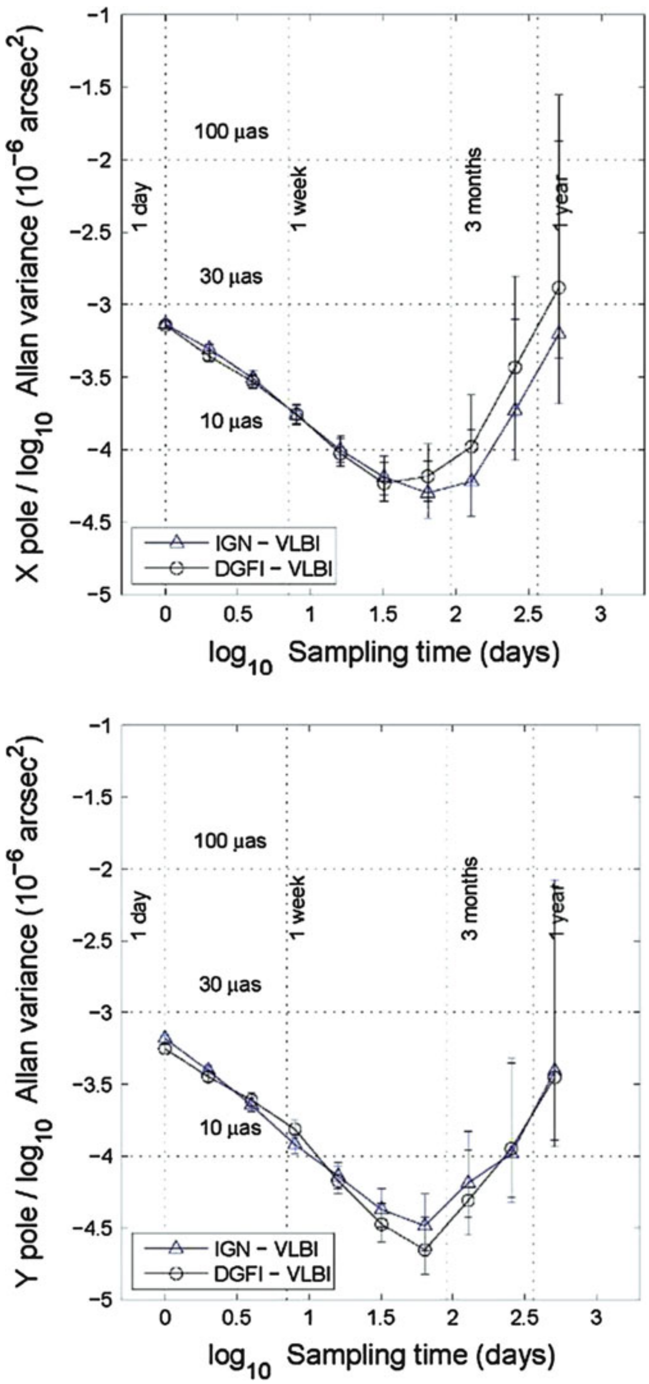

Fig. 9.7 Allan variance between IGN and DGFI solution EOP and VLBI TRF EOP

significant difference in the agreement of the DGFI and IGN solutions with the TRF solution. The WRMS differences between EOP (X, Y, UT1) estimates from the VLBI TRF solution and the IGN (DGFI) solution are 52 μas (46 μas), 46 μas (42 μas), and 3.3 μs (3.3 μs) respectively. Agreement is at the 1-sigma level and is slightly better for DGFI.

The effect on the estimated CRF using the IGN or DGFI a priori TRFs is not significant. The CRF XYZ frame rotation angles (in mas) between the IGN (DGFI) solutions and the full VLBI TRF solution are only 0.026 ± 0.050 (0.050 ± 0.050), -0.020 ± 0.060 (-0.023 ± 0.060), and 0.000 ± 0.020 (0.003 ± 0.020). WRMS differences (in mas) between source positions after taking out the rotation angle differences are only 0.011 (0.009) in declination and 0.005 (0.003) in right ascension.

4 Conclusions

We have compared the IGN and DGFI TRFs with the TRF estimated from a GSFC operational-type CALC-SOLVE solution. For the 40 most frequently participating stations, the WRMS differences are 2–3 mm in position components and 0.3–0.4 mm/year for velocity components. The scale difference between the GSFC TRF solution and the IGN/DGFI solution is $-0.39/-0.09$ ppb. This IGN scale difference occurs because IGN found a scale difference of -1.05 ppb between the SLR and VLBI and input solutions and then weighted the two solutions equally in their combination. Possible explanations for the difference between the scales of the IGN and DGFI solutions are differences in their treatment of site ties and more generally differences between their strategies used to define the TRFs. But these are questions that would need to be addressed by IGN and DGFI.

There are large differences between GSFC and DGFI and/or IGN positions/velocities for a large number of sites including Japanese domestic sites, mobile VLBI sites in North America that observed in the 1980s and early 1990s, and other VLBI stations that have not observed recently.

We also evaluated the effect of using the IGN or DGFI TRFs in CALC/SOLVE solutions. Fixing the positions and velocities to either IGN or DGFI solutions yield EOP series that agree with the IGS combined series equally well within formal uncertainties. The DGFI solution EOP estimates agrees slightly better than the IGN solution with a GSFC VLBI TRF solution where positions and velocities are estimated. Both solutions agree with the TRF solution within formal uncertainties.

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